DS1 Primary Mission

- Primary mission complete
  - Exceeded technology validation objectives
    - 3,500 hours on Ion Propulsion System (IPS)
  - Conducted DS1 Technology Validation Symposium in Pasadena on February 8-9
    - Over 100 attendees from industry, academia, NASA and other government agencies
    - All 12 technologies presented the results of validation on DS1

Primary Mission Success Criteria

1) Demonstrate the in-space flight operations and quantify the performance of the following advanced technologies:
   - Solar electric propulsion
   - Solar concentrator arrays
   - Small deep space transponder
   - Miniature camera and imaging spectrometer
   - Autonomous navigation

   and 3 of the 6 following advanced technologies:
   - Autonomous remote agent
   - Beacon monitor operations
   - K_a-band solid state power amplifier
   - Low power electronics
   - Multifunctional structure
   - Power actuation and switching module
2) Acquire the data necessary to quantify the performance of these advanced technologies by September 30, 1999. Analyze these data and disseminate the results to interested organizations/parties by March 1, 2000.
3) Utilize the on-board Solar Electric Propulsion (SEP) to propel the DS1 spacecraft on a trajectory that will encounter a near-Earth asteroid in FY 1999.
4) Assess the interaction of the SEP system operations with the spacecraft and its potential impact on charged particle, radio waves and plasma, and other science investigations on future SEP propelled deep space missions.

Extended Mission Status

- Conducted new, extensive calibrations of MICAS
  - Visible channels (CCD, APS)
  - IR
- Acquired Mars IR spectra
  - Highest resolution spectra in 1.3 - 2 μm region ever obtained for Mars
- Conducted final UV diagnostic measurements
- Attempted PEPE operations at higher voltage levels (above the nominal 8kV); a discharge event in the Time-of-Flight (TOF) unit caused temporary suspension of the instrument operations
  - Discharge event thoroughly investigated
  - PEPE electron and total ion measurements unaffected by the event
  - Ion composition data from TOF analyzer will be of lower but usable quality

Extended Mission Status - Cont'd.

- All spacecraft subsystems, except the Stellar Reference Unit (SRU), are healthy.
- Spacecraft in Sun standby since 11 November 1999, when the SRU stopped providing attitude data; attempts to revive SRU have not been successful
  - Worked with the vendor to understand the cause of SRU failure
  - Investigation shows that PEPE discharge is unrelated to SRU failure.
- In December, project shifted focus from troubleshooting SRU to developing techniques for conducting a mission without SRU
  - Determined that it will not be possible to reach both extended mission targets and proposed a single target (Comet Borrelly) mission
  - All project work is devoted exclusively to returning science from Comet Borrelly

Star Tracker Anomaly

- No attitude data from SRU since 11 November 1999, 14:51 UTC
- ISA written
- Analysis team, consisting of DS1 flight team, JPL star tracker experts, and engineers at Lockheed-Martin, has been pursuing the cause of the anomaly
  - Symptoms:
    - Anomalous power consumption (up to ~ three times normal), starting at about 1 hr prior to the anomaly and continuing for a period of time after the anomaly
    - Even after power consumption returned to normal, SRU never came back to life
    - All housekeeping data showing a constant value (132 DN)
  - Tried 9 sec and 5 min power cycles to fix the problem, but without success
  - Ground test on the SRU qualification unit at Lockheed Martin reproduced some of the signatures seen on the spacecraft but not all
  - Suspect more than one component has failed
  - It is unlikely that the SRU can be revived
- An "SRU Anomaly Close-Out" review is being planned for April

MICAS UV Channel

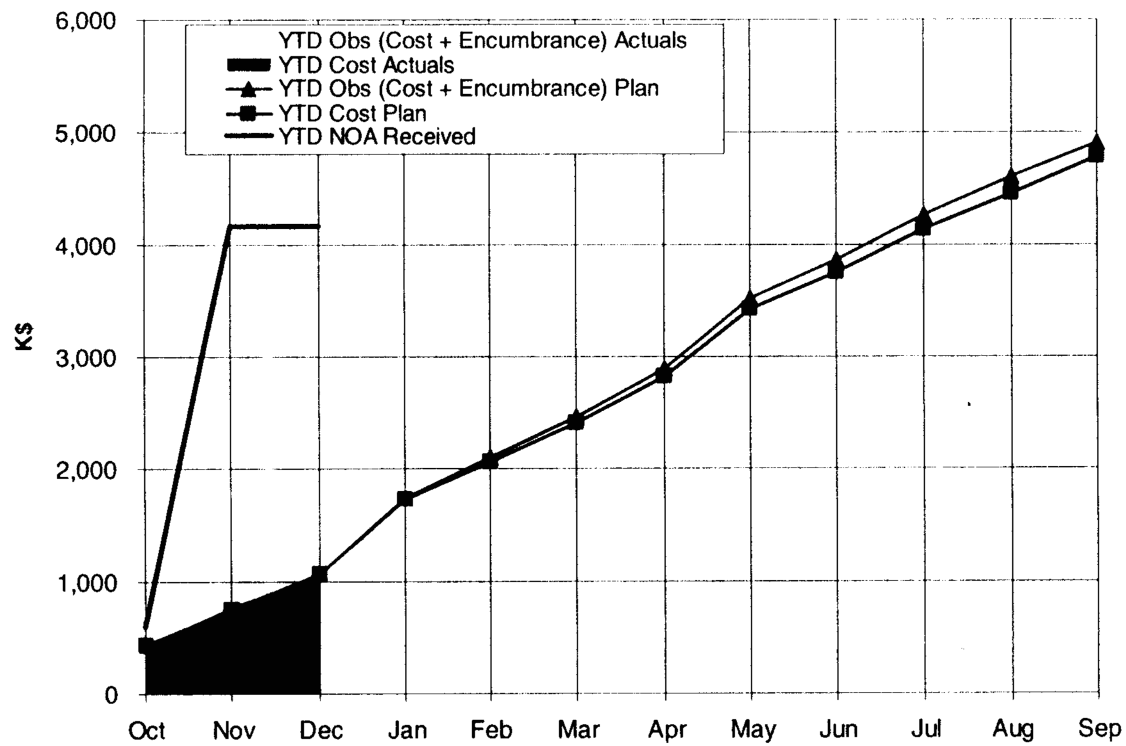
- MICAS UV high voltage supply is stuck "on"
  - Repeated attempts to turn high voltage off have been unsuccessful
  - Does not affect operation of other MICAS channels
- UV channel has not worked since launch
- Science team declared UV channel "dead" at its meeting in January 2000

PEPE TOF Discharge Event

- Conducted two reviews, one at JPL and the other at SwRI, with participation of PEPE instrument team (PI and instrument engineers) and JPL experts, to understand the anomaly and the status of the instrument
  - No damage to PEPE electronics
  - No collateral damage in electron sensor
  - Ion sensor damage does not affect measurements of total ion distributions.
  - Ion composition measurements degraded in sensitivity and resolution; still under investigation.
  - PEPE electron measurements unaffected by the event
  - Science data taken after anomaly show instrument is otherwise in good health
  - Both electron and total ion channels will return useful high resolution data on solar wind and cometary coma
  - Plan for investigation of TOF operation and scientific value of TOF measurements (ion composition) is being worked
- Investigation showed that PEPE does not pose a risk to the spacecraft health and safety

Deep Space 1

Budget Status



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
NOA Received	600	4,165	4,165									
Cost												
YTD Plan	439	762	1,073	1,729	2,058	2,408	2,809	3,423	3,747	4,128	4,452	4,775
YTD Actuals	412	793	1,041									
Variance	(27)	31	(32)									
Obligations												
YTD Plan	439	762	1,073	1,747	2,094	2,462	2,881	3,513	3,855	4,254	4,596	4,900
YTD Actuals	412	809	1,057									
Variance	(27)	47	(16)									

NARRATIVE:

Obligations:

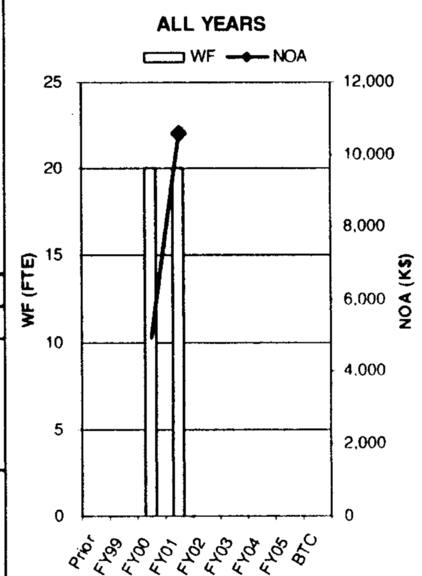
1) Labor rate below plan	(32)

Costs:

1) Labor rate below plan	(32)
2) delayed billing - P.O.	16
net	(16)

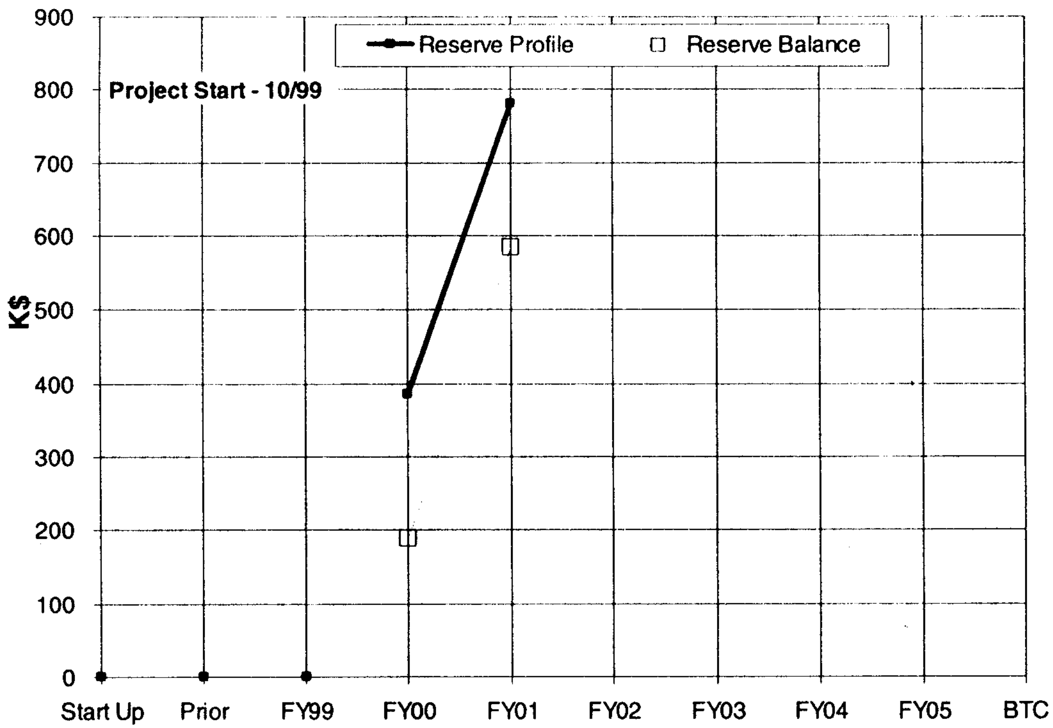
Reserves:

YTD Unencumbered	189



Deep Space 1

Reserve Status



	Start Up	Prior	FY99	FY00	FY01	FY02	FY03	FY04	FY05	BTC
Reserve Profile	0	0	0	386	781	0	0	0	0	0
Reserve Balance	0	0	0	189	584					
Approved Liens	0	0	0	197	197					

Remaining Effort Less Reserves	Reserve Balance	Percentage of Reserves to Remaining Effort	Reserve Threats
9,770	189	1.9%	0

RESERVE UTILIZATION	
Star Tracker Anomaly - ACS	165
PEPE Anomaly	32
Total Reserve Utilization	197

Mission Update

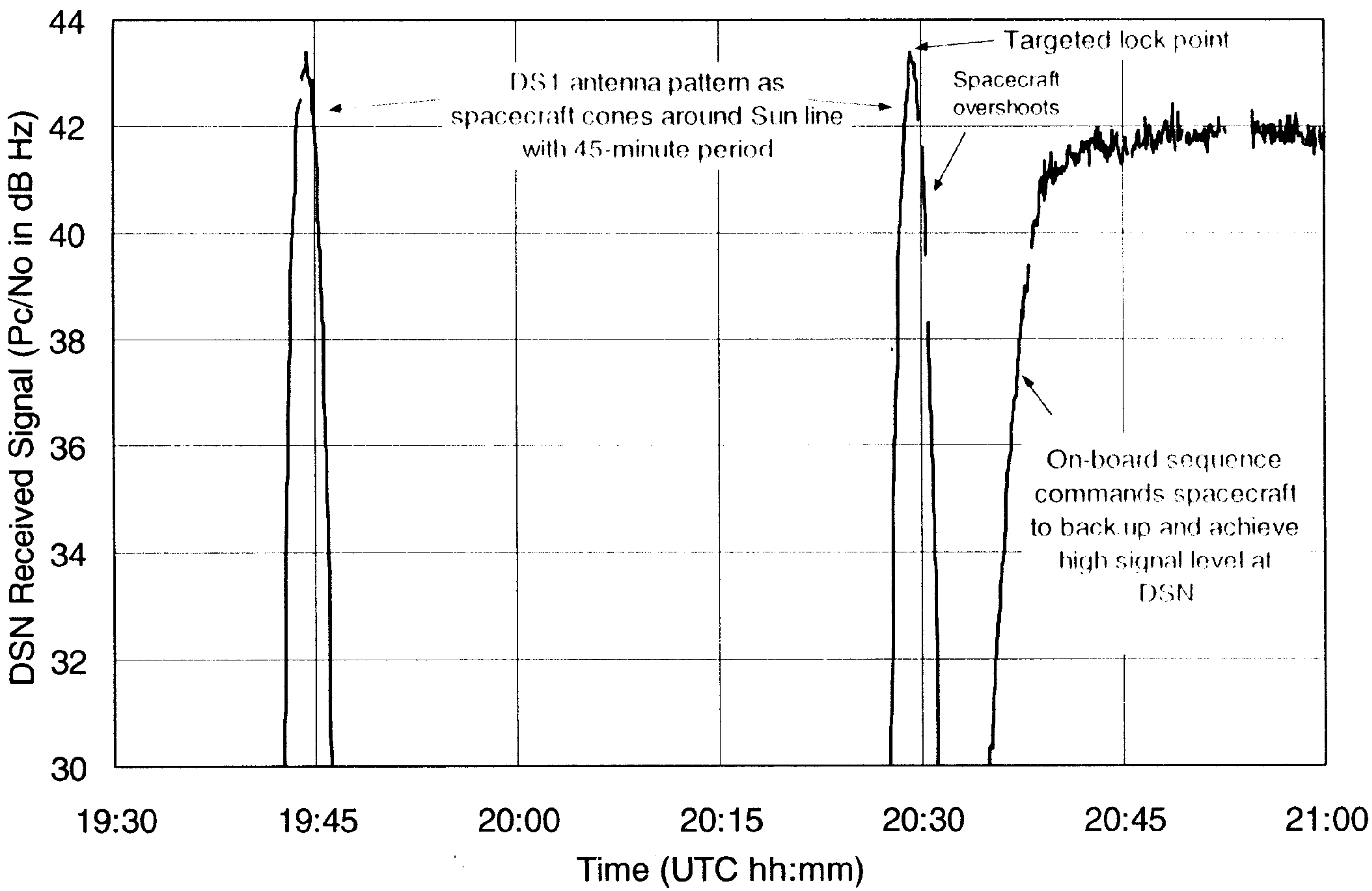
Marc Rayman

Current Alternative to SRU

- Current method of high gain antenna (HGA) pointing relies on using signal strength at DSN as error signal for pointing. Procedure:
  - Spacecraft offsets HGA from normal Sun-point by Sun-probe-Earth angle in arbitrary direction.
  - Spacecraft cones around Sun line, thus sweeping HGA through Earth.
  - Received signal at DSN reveals phase of rotation. Time of next HGA-on-Earth peak is computed.
  - Command to stop coning is transmitted (allowing for round-trip light time, time for DSN to sweep uplink frequency to acquire uplink on board, and other delays). Known lag on spacecraft is accounted for.
  - Attitude corrections sent as real-time commands as needed (~ 1/hr).
- This technique to be used regularly until new software is loaded.

Deep Space 1

DS1 Signal at DSN



Replacement for SRU

- Plan under development uses visible CCD in miniature integrated camera spectrometer (MICAS) in place of SRU. Key differences between SRU and MICAS:

Parameter	SRU	MICAS
Field of view (FOV)	$8.8° \times 8.8°$	$0.69° \times 0.78°$
Limiting magnitude	7.5	5 – 9 (attitude dependent)
Output data	quaternion	image file
Output rate	4 Hz	0.04 Hz

- *Principal challenge*: in an arbitrary attitude, the probability of a detectable star pattern being in the MICAS FOV is too low.
- *Solution*: Constrain spacecraft to attitudes such that

  1) 1 and only 1 preselected star of sufficient magnitude is in the MICAS FOV,

  or

  2) duration at attitude is short enough to use gyros.

Replacement for SRU - Cont'd.

- In contrast to primary mission, for remainder of extended mission, only 4 classes of attitudes are needed:
  - HGA on Earth
  - Ion propulsion system (IPS) thrust
    - New IPS thrust plan developed that uses discrete inertial thrust vectors rather than nearly continuously updated vector.
  - TCMs
  - Science data acquisition at Borrelly

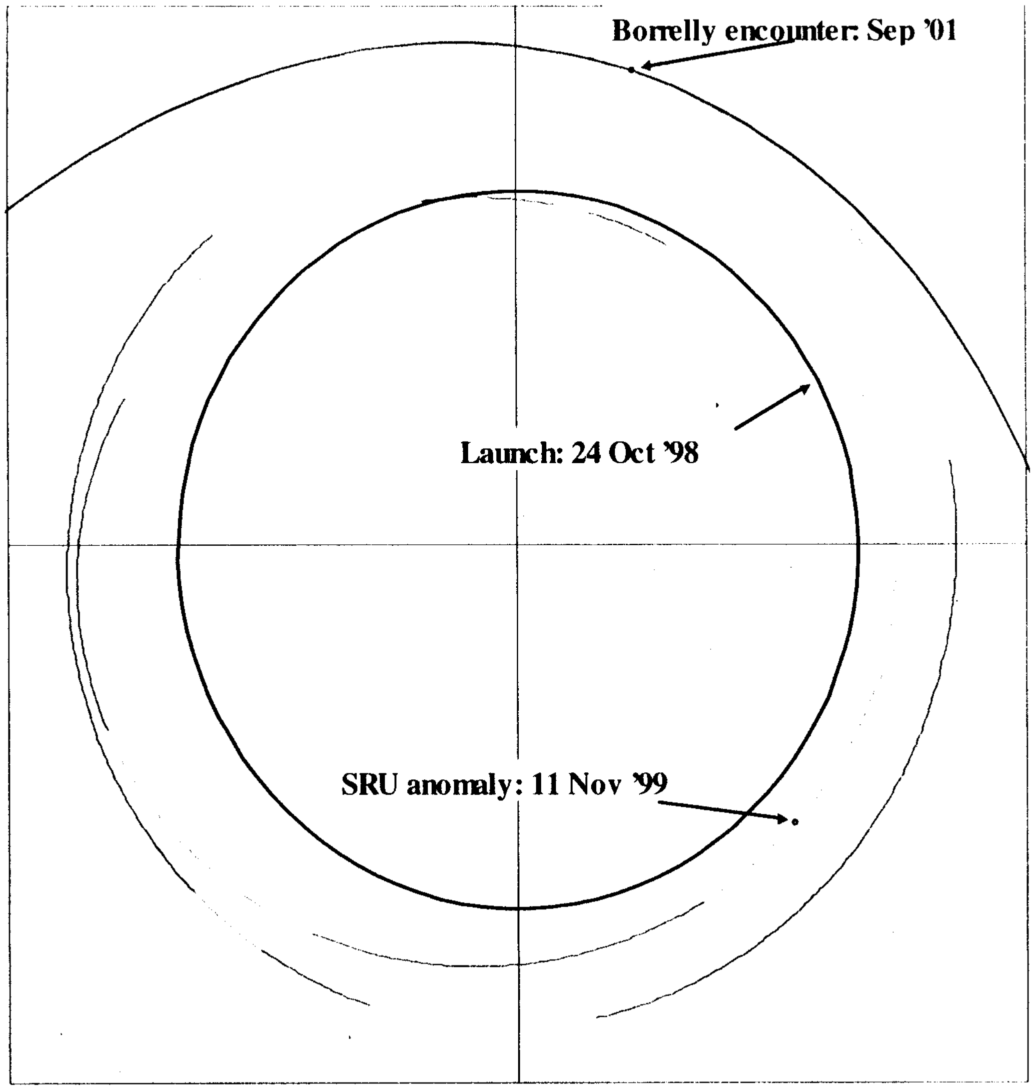
System Enhancement for SRU Replacement

- Principal new flight software features:
  - Acquire, process, and incorporate into attitude estimator MICAS images
    - Builds upon capabilities of autonomous navigation system
    - Capability to mosaic in the event star is not present
  - Make more use of Sun sensor data
    - Some ACS modules previously did not use Sun sensor because SRU made it unnecessary
- Options for reacquisition of attitude in case of a safing event:
  1) Use received signal strength (same as current HGA pointing technique). This will not work well when Sun-probe-Earth angle is small.
  2) In standard safe attitude (HGA Sun-pointed, MICAS 90° from Sun), rotate 360°/4 hours. Sequence has MICAS acquire image strip throughout rotation, AutoNav processes each image to find bright stars, time-tagged locations are transmitted to ground, and ground-processing establishes attitude.
- New software to be radiated to spacecraft and installed in May.
  - Procedure well understood.
  - Software was replaced 3 times during primary mission.

Developmental Tests for New Control System

- To increase confidence in new system, several developmental tests have been conducted on the spacecraft
  - MICAS transfer test
    - Acquire and transfer 1 MICAS image every 30 seconds
    - End-to-end test of camera, data interface board, and central computer during various spacecraft activities and computer loading profiles
    - Test to continue for 2 weeks or longer (started on March 16)
  - MICAS scattered light test
    - Acquire and return MICAS images at the low solar angles needed for attitude control during IPS thrusting
    - Verification of predicted scattered light signature at unexplored attitudes. (If MICAS were not replacing SRU, images would not be taken at these angles.)
    - Test completed on March 16; analysis of data under way
  - Spacecraft stability test
    - In safe state, reduce spacecraft rate to minimum and acquire deep MICAS images
    - May be used for recovery of attitude in the case of a safing event
    - Test completed on March 16; analysis of data under way

Trajectory


Borrelly encounter: Sep '01
Launch: 24 Oct '98
SRU anomaly: 11 Nov '99

Borrelly Encounter Planning

- Encounter software to be loaded in February 2001.
- First encounter rehearsal (February '01) to aid in verifying new software load and to validate encounter sequence development.
- Second encounter rehearsal (June '01) to incorporate lessons from first and input from encounter planning review board.
- Encounter plan to be based on prioritized science requirements.
- Target tracking to be initiated as late as possible in approach.
  - Expect > 50 pixel image of nucleus before beginning target tracking.

Key Mission Parameters

Date of closest approach to Borrelly	late Sept '01
Time after perihelion	~ 10 days
v_∞	17 km/s
Encounter phase (Sun-body-s/c)	90°
Heliocentric range at encounter	1.36 AU
Geocentric range at encounter	1.5 AU
Solar elongation at encounter	63°
Resumption of thrusting	mid June '00
FSW load opportunities (already in DSN schedule)	May '00 + Feb '01
Solar conjunction	11/11/00
Duration of Sun-Earth-Probe angle < 2°	18 days
Encounter rehearsals	Feb '01 + Jun '01
Coast prior to encounter	3 months

Science Objectives

Robert M. Nelson

Comet Flyby Fundamental Scientific Issues

- Understanding processes governing the origin and evolution of the solar system, protoplanetary disks, and planetary formation in general, all key issues relevant to NASA's strategic plan.
- Physical structure of cometary nuclei: icy conglomerate, "rubble pile," or other?
- Chemical composition of comets: identification of parent volatiles and chemical diversity of comets in the solar system (i.e., differences between comet families).
- Origin and nature of cometary activity and evolutionary effects.
- Nature of the solar wind interaction with comets, plasma processes and structures including the ion and electron energetics.

Science Implementation Issues

- New mission design constraints as a consequence of the star tracker failure prohibited a two flyby mission
- At science team meeting in January the group selected Borrelly over Wilson-Harrington based on the expected science return
- Physical processes in the near-nucleus coma (within 50 km of the nucleus) will be observable with remote sensing instruments. At 2000 km SWIR resolution ~100m and CCD resolution ~20m
- The remote sensing data will be complemented by *in situ* data of the environs 1000-2000 km from the nucleus.

Scientific Rationale for DS1 Borrelly Flyby

- First NASA mission to a comet instrumented with a spectral remote sensor (IR to visible) and the ability to perform compositional analyses. MICAS and PEPE/IDS complement each other.
- ***MICAS***
  - IR yields spectral reflectance of surface minerals and ices, and dust in the coma.
  - CCD and APS map the nucleus, and to a lesser extent, the coma and tail morphology.
- ***PEPE and IDS***
  - *In situ* ion and electron velocity distributions along the s/c trajectory, not detectable from Earth. Extends our knowledge to lower energies of the largest electron component in the inner coma and possible identification of negative ions.
  - Study of the solar wind interaction and plasma structures in the cometary environment.
- Close flyby permits studies of cometary phenomena too faint to be seen from Earth.
- DS1/Borrelly allows the encounter of a scientifically exciting object very soon, before any planned missions to comets.
- Borrelly justifies a mission on its own merits, so DS1/Borrelly great scientific value for cost to investigate primordial material in the solar system.

Goals of DS1 Borrelly Mission

- Obtain the first spatially resolved IR spectral images of a cometary nucleus.
- Gain information on the chemical composition and surface distribution of parent volatiles in the nucleus and sources of coma gas (subsurface, surface, and dust).
- Compare and contrast solar wind interaction and plasma structures at Borrelly with other comets. Search for and characterize "hot" ions in the inner coma first seen at Halley.
- Measure *in situ* electron densities and energetics along the spacecraft trajectory to provide knowledge of the large component of low energy electrons in the inner coma and search for negative ions.
- Investigate nature of cometary activity: gas and dust jets, surface active regions, day/night asymmetries.
- Study physical and chemical processes that occur in an Edgeworth Kuiper Belt escapee.

Status of Instruments

1) MICAS

   CCD fully operational

   APS fully operational

   IR spectrometer fully operational

   UV spectrometer non-functional

2) PEPE

   Ion and electron velocity distribution measurements

   HV operation testing in cruise will define the new limits of the ion composition measurements.

3) All Ion Diagnostic Sensors are fully operational

Preliminary Observational Objectives

Level of Difficulty One (Lowest)

- Image of nucleus (~50 pixels or better) and IR spectroscopy only.
- Full *in situ* ion and electron density, flow velocity, and temperature measurements along trajectory

Level of Difficulty Two

- Best effort inbound/outbound image of tail
- Ion composition measurements in limited spectral range

Level of Difficulty Three (Highest)

- High resolution images of the nucleus (50-100 m-SWIR, 10-20m-CCD)

Significance of Results

A successful Borrelly flyby will:

- Determine the shape, volume and albedo of the nucleus
- Lead to a fuller understanding of the complex interactions of the solar wind with the plasma and neutral gas created by cometary activity
- Constrain the phase functions of the nucleus and the near-nucleus dust
- Determine the size of observed landforms and of active areas on the nucleus
- Constrain the dust emission from "inactive" areas and the night side
- Investigate the effects of thermal inertia on dust emission
- Investigate the origin of "filaments" in the inner coma
- Compare the derived results with the only previous resolved measurements of a cometary nucleus and inner coma (Halley)

Consequences of the Expected Results from DS1 Borrelly Mission

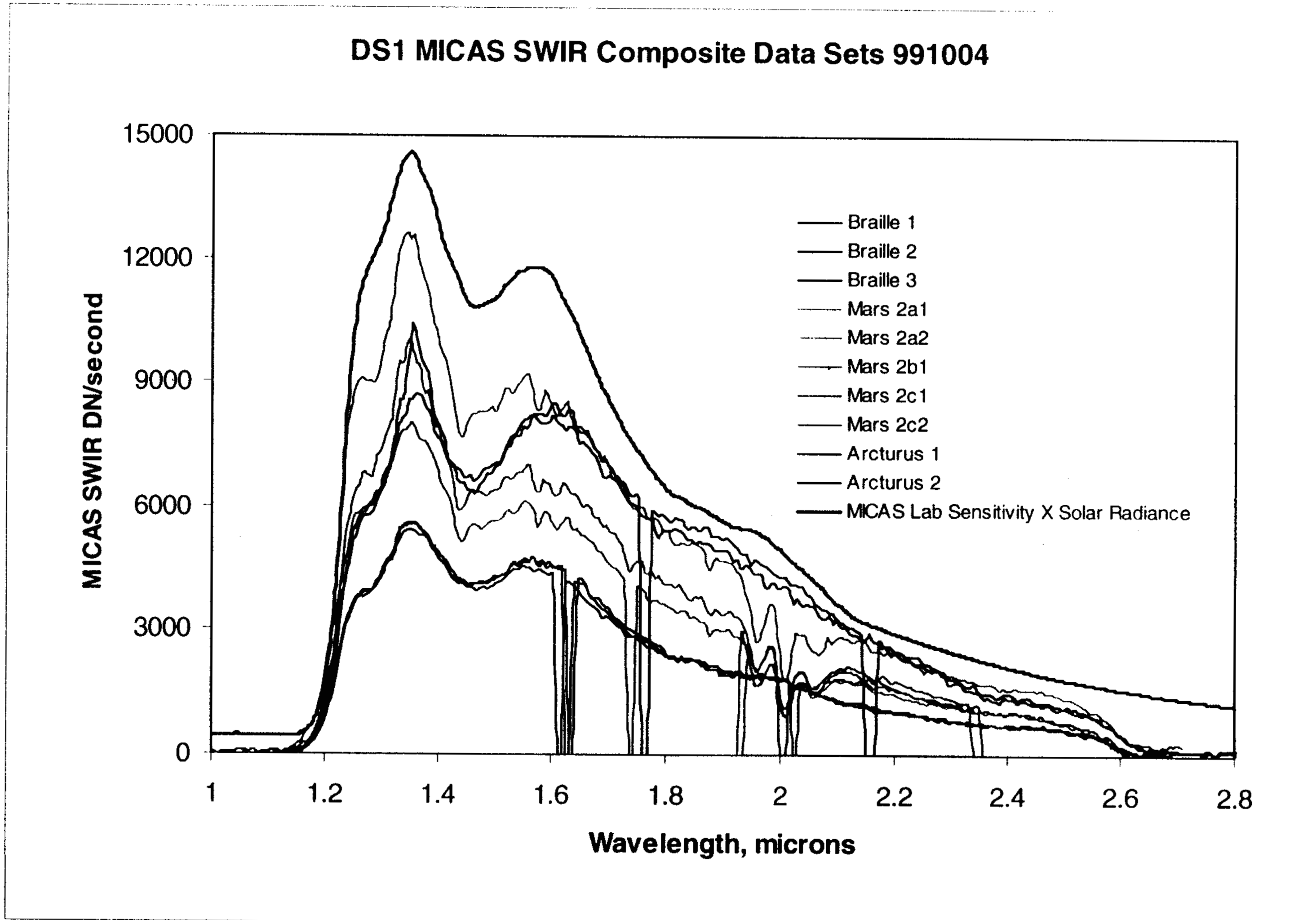
- Improved understanding of key questions of the origin and evolution of the solar system and the chemical basis from which life evolved.
- Great leap in knowledge of cometary science for distinguishing between competing models of comets.
- Aid in planning and refining future cometary rendezvous and sample return missions. Crucial precursor to CONTOUR, Deep Impact, CNSR, Stardust and Rosetta missions.

DS1 Mars Science Results

- The MICAS SWIR imaging spectrometer provides 170 spectral channels (1.2-2.4μm) in 216 spatially resolved 54-μrad fields-of-view and uses an advanced Rockwell NICMOS-4 detector (funded during research and development of the MICAS PIDDP precursor: PICS).
- SWIR spectra of Mars were acquired from a range of ~110 million km (phase~50°) and provide one of the best full-up end-to-end tests of the MICAS integrated multi-wavelength SiC optical system.
- Although these spectra were heavily contaminated with stray sunlight, they far exceed the quality of any existing Mars reflectance spectra in the 1.3-2.0μm range.
- Numerous CO_2 bands, and new unidentified spectral features are recognized. It has been suggested that these new features pertain to surface composition.

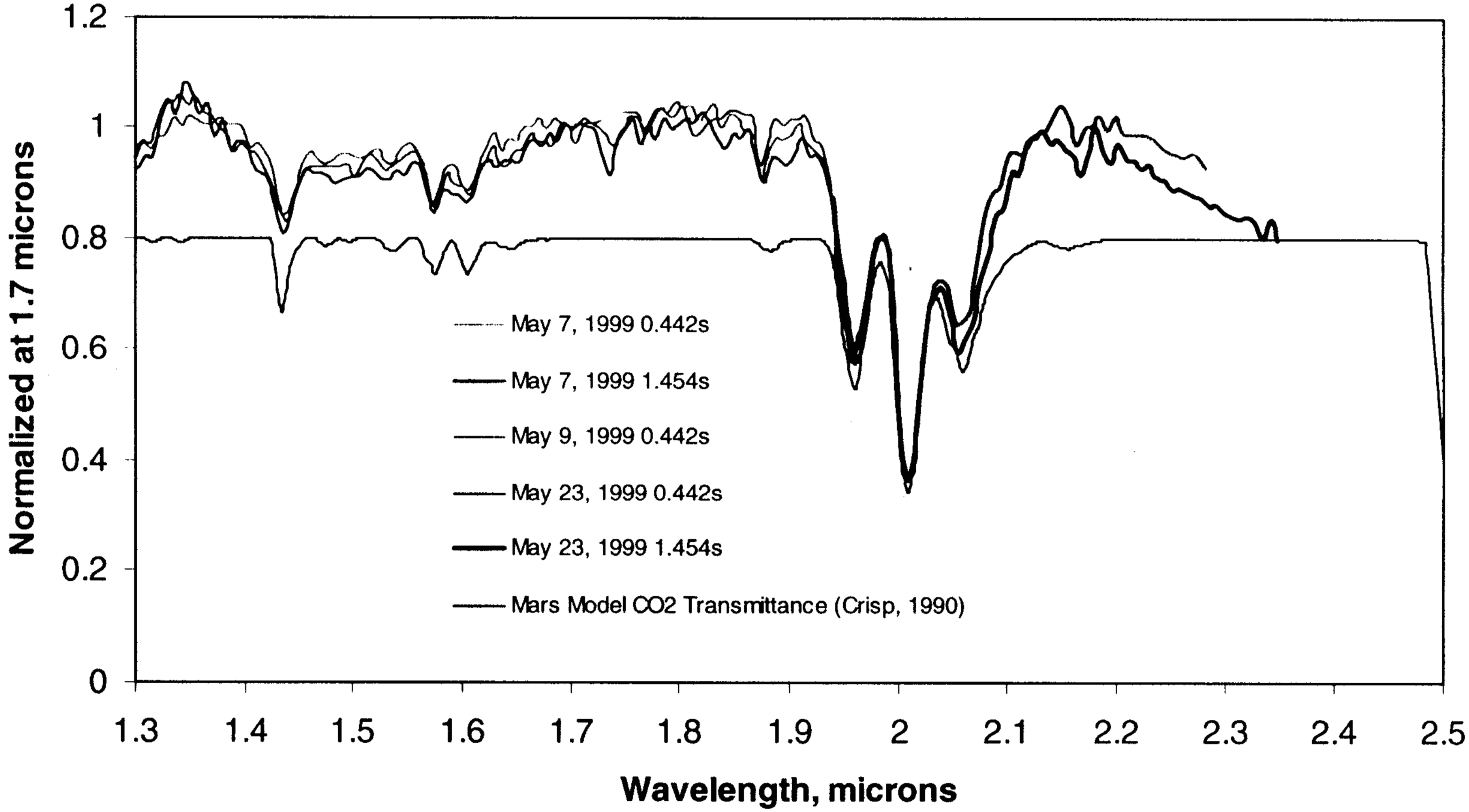
Deep Space 1

MICAS Raw Spectra



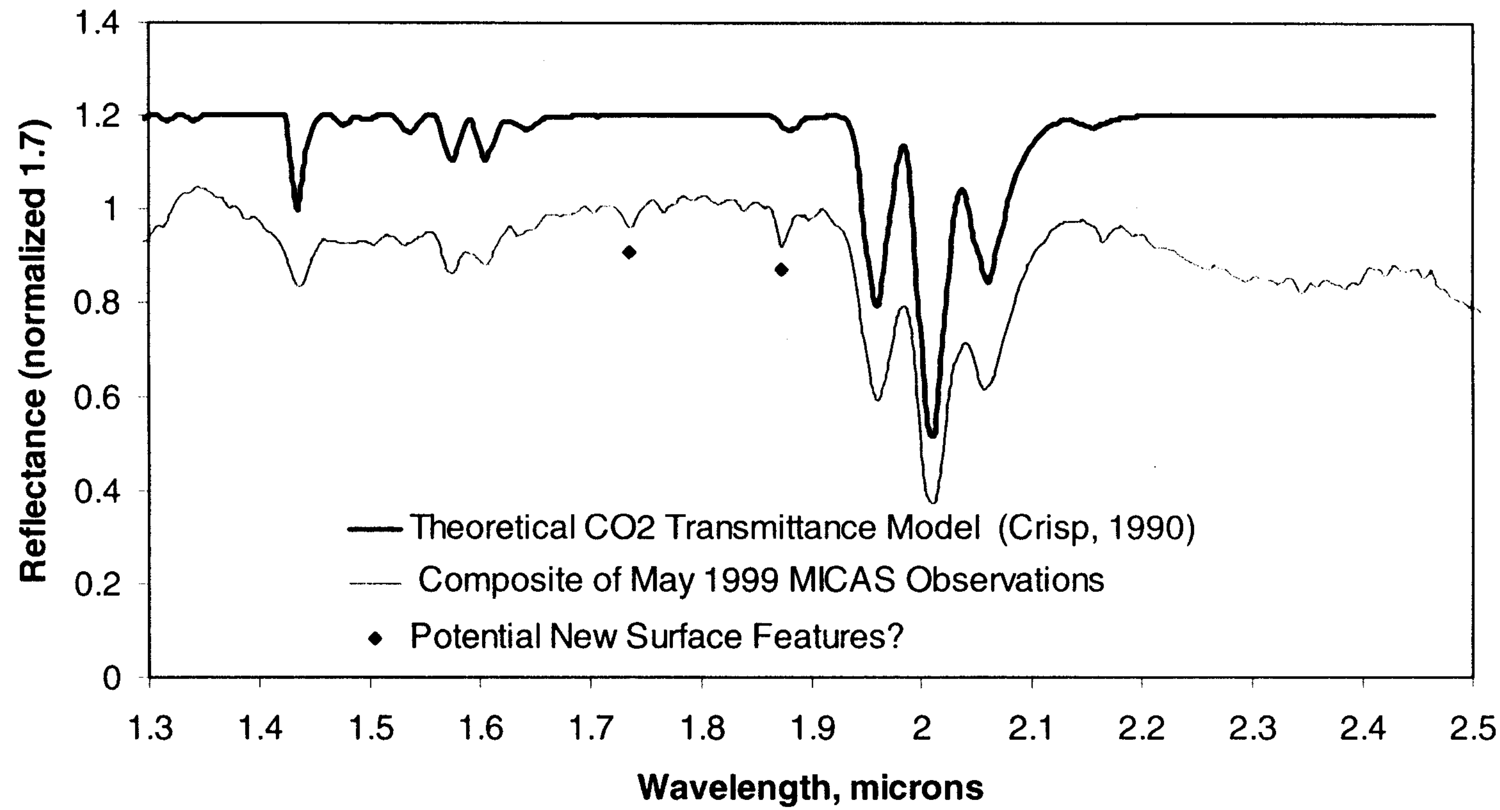
Deep Space 1

MICAS Corrected Spectra



Deep Space 1

Composite of Mars Spectra



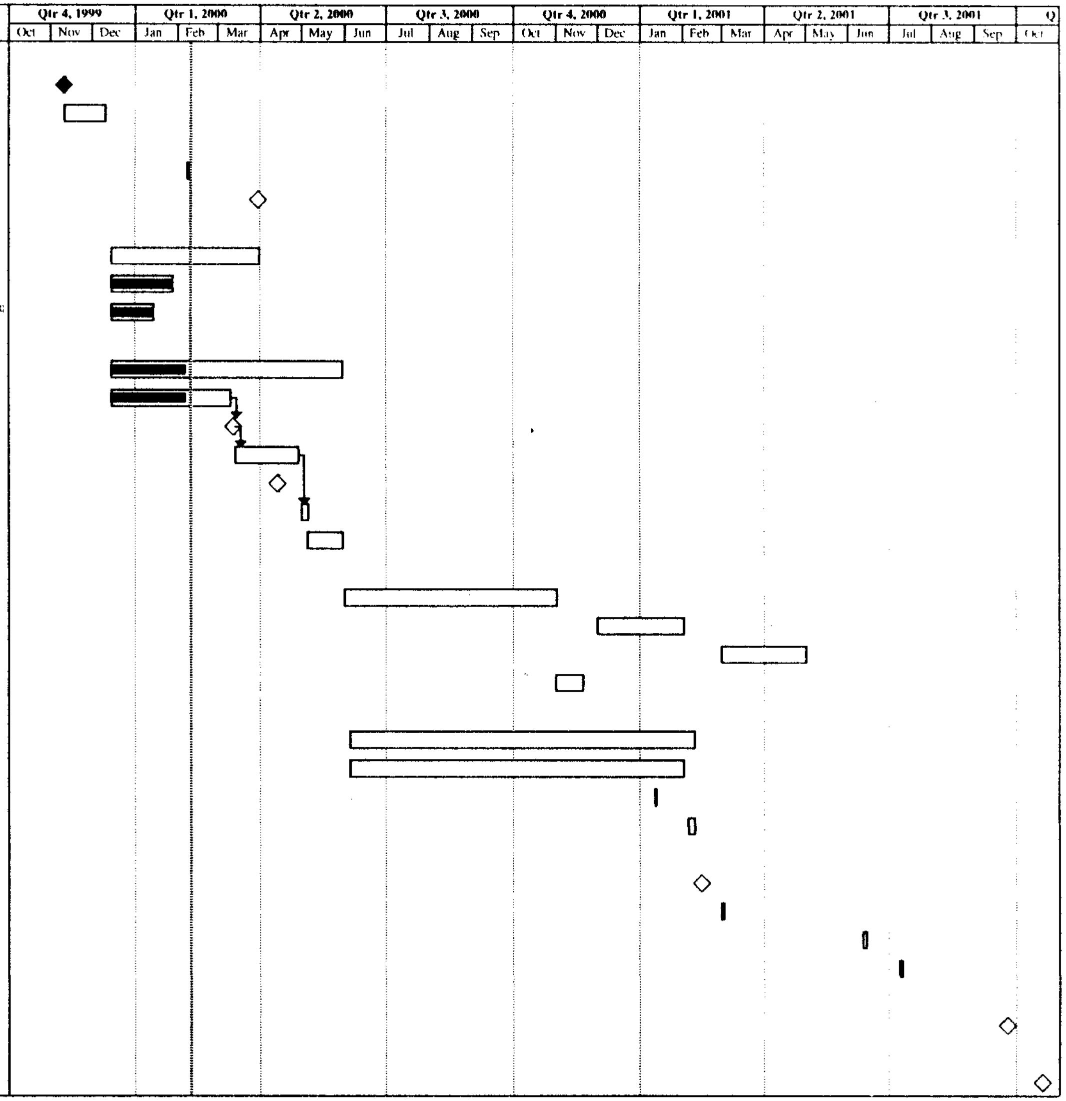
Summary

Phil Varghese

Deep Space 1

Master Schedule

ID	Task Name
1	EXTENDED MISSION START
2	< SRU Failure >
3	Attempt SRU Recovery
4	
5	Technology Validation Workshop
6	Lessons Learned Workshop
7	
8	**Replan for Mission without SRU**
9	Develop Prelim Plan
10	Develop & Validate New HGA Pointing technic
11	
12	FSW M6F2:
13	Design/Implement FSW Changes
14	Deliver Test Version to Testbed
15	Conduct Testing
16	Readiness Review
17	M6F2 Load & Reboot
18	In-Flight Checkout
19	
20	**IPS Thrust Arcs for Borrelly Encounter**
21	
22	
23	Solar Conjunction Period
24	
25	FSW M7:
26	Develop & Test
27	Readiness Review
28	M7 Load & Reboot
29	
30	Encounter Rehearsal #1
31	Encounter Plan Review
32	Encounter Rehearsal #2
33	Encounter Readiness Review
34	
35	**Borrelly Encounter**
36	
37	**End of Extended Mission**



Team Assessment

- A scientifically compelling mission with Comet Borrelly as the encounter target is doable and affordable within the current allocation of resources.